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Loftus et al.

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(54) **METHOD AND APPARATUS FOR HIGH-VOLTAGE DC CHARGING OF BATTERY-ELECTRIC AND PLUG-IN HYBRID ELECTRIC VEHICLES**

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(52) **U.S. Cl.**

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CPC B06L 11/1809; B06L 11/1816; B06L 2210/12; B06L 2210/14; B06L 2210/30; B06L 11/1818; Y02T 10/7005; Y02T 10/7088; Y02T 10/7225; Y02T 10/7233; Y02T 10/7241; Y02T 90/121; Y02T 90/127; Y02T 90/14; Y02T 90/16

USPC 320/104, 105, 109

See application file for complete search history.

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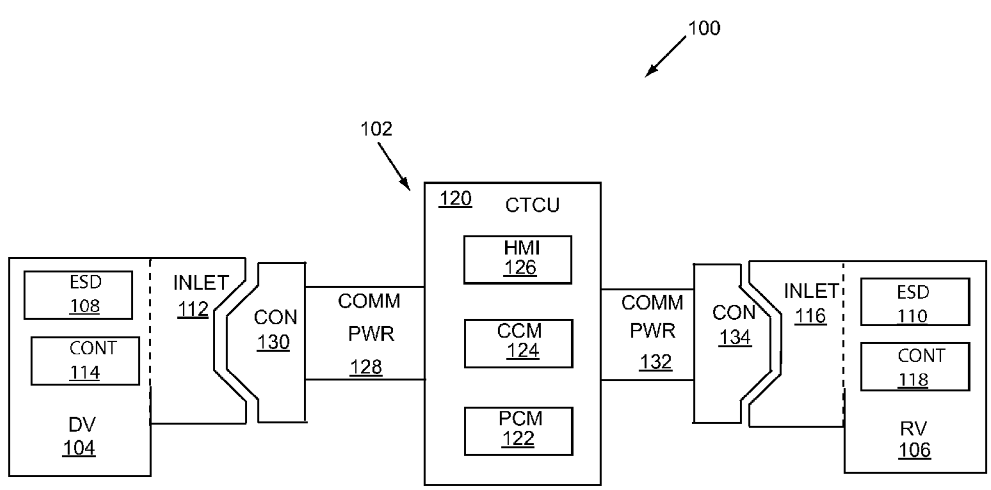
(57) **ABSTRACT**

A portable charging device can provide controllable fast DC charging of an electric vehicle (EV) high voltage battery by a separate EV high voltage battery. The charging device can be configured to comply with universal standards for EV charging so as to be compatible with various automobile models of various manufacturers. The device can be configured to establish a communication link with a donor and recipient vehicle and conduct a voltage matching process between the batteries of the two vehicles prior to transferring power to the recipient vehicle battery. To prevent energy theft, control of a charging process can be shared among the charging device and the donor and receiver vehicles. A charger device can be configured to enable a charging process only when no faults are detected. A charger device can allow a motorist to quickly recharge a depleted high voltage battery at a convenient time and location.

20 Claims, 6 Drawing Sheets



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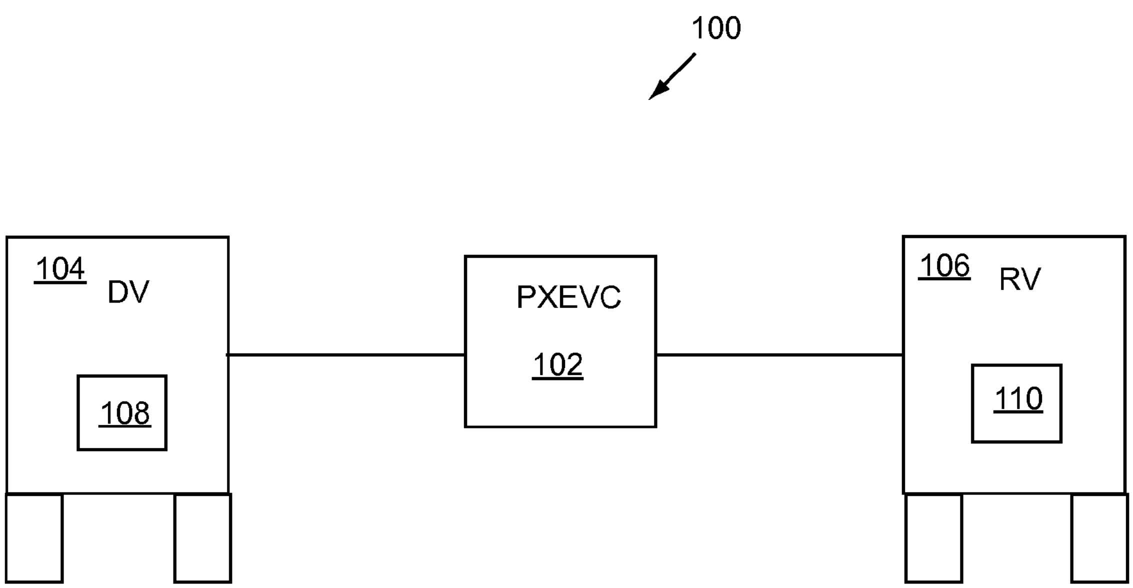


FIG. 1

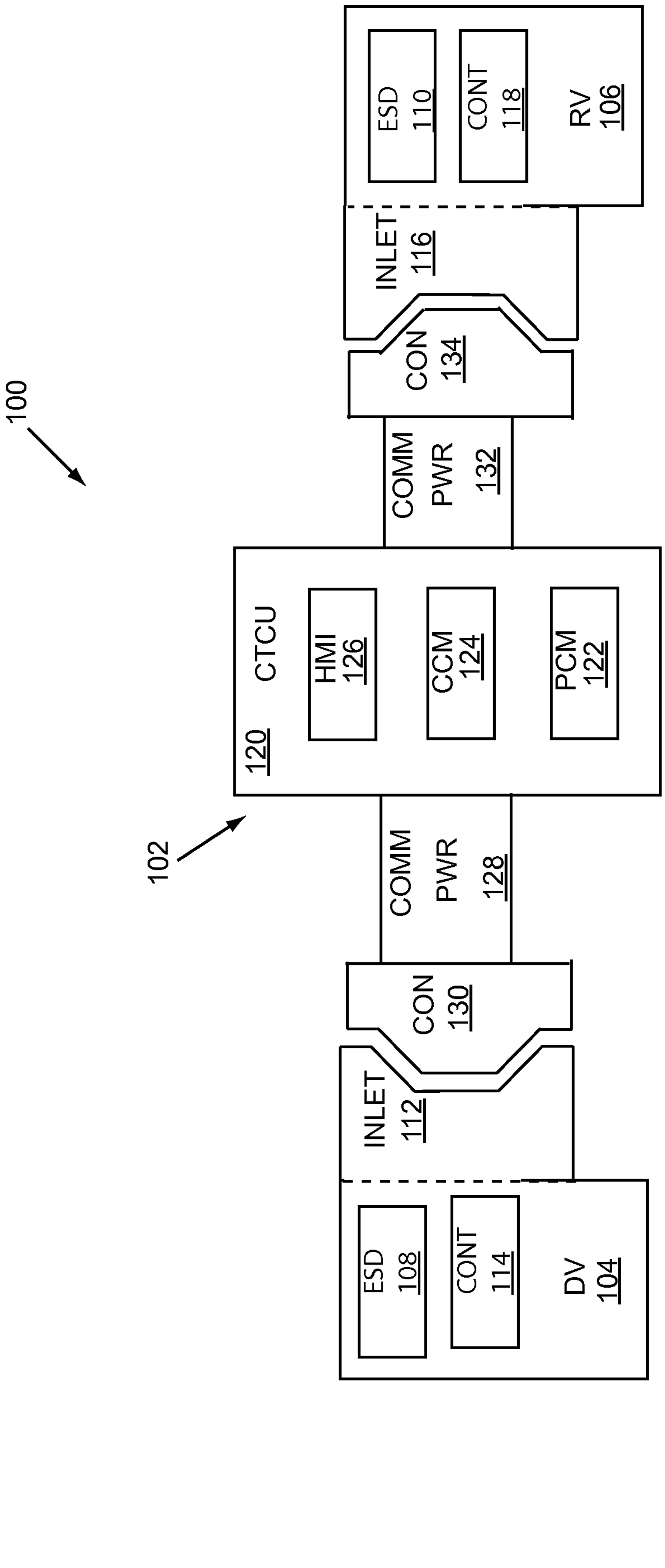
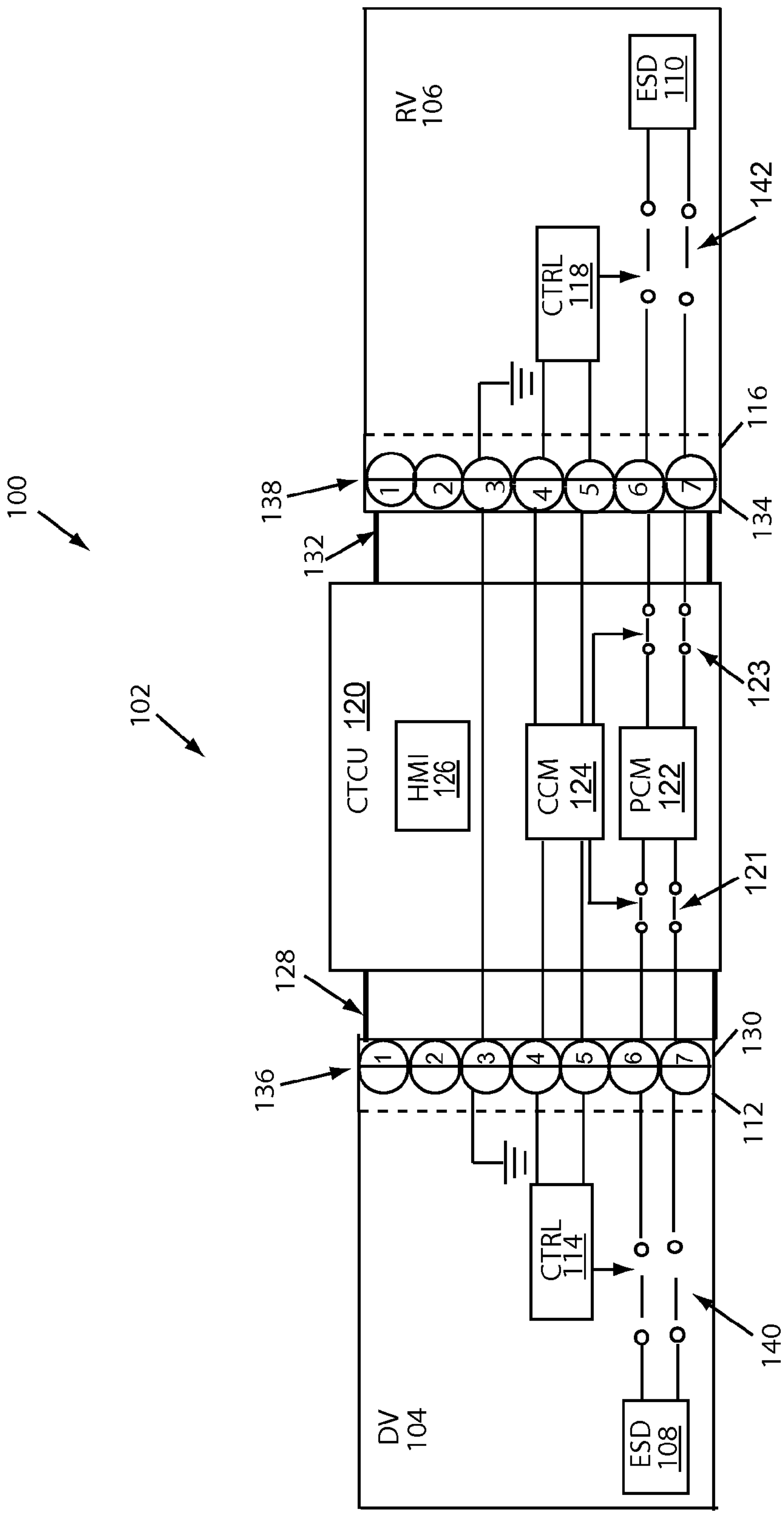

100
ESD
110
CONT
118
RV
106
INLET
116
CON
134
COMM
PWR
132
CTCU
120
HMI
126
CCM
124
PCM
122
102
COMM
PWR
128
CON
130
INLET
112
ESD
108
CONT
114
DV
104

FIG. 2


100
102
RV
106
ESD
110
142
CTRL
118
116
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134
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123
CTCU 120
HMI
126
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PCM
122
121
128
136
130
112
CTRL
114
140
DV
104
ESD
108
1
2
3
4
5
6
7

FIG. 3

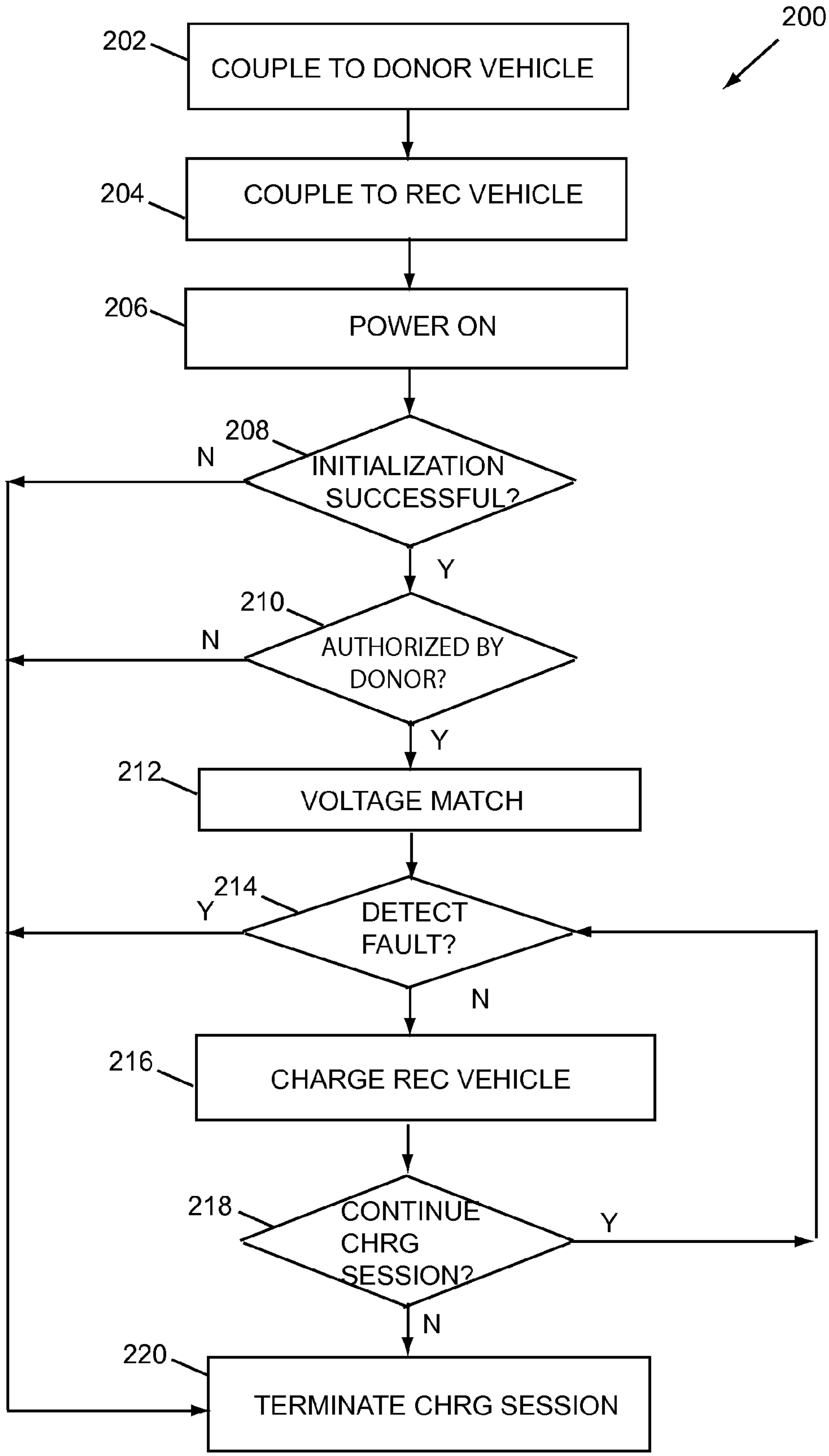
200
202
COUPLE TO DONOR VEHICLE
204
COUPLE TO REC VEHICLE
206
POWER ON
208
INITIALIZATION SUCCESSFUL?
N
Y
210
AUTHORIZED BY DONOR?
N
Y
212
VOLTAGE MATCH
214
DETECT FAULT?
Y
N
216
CHARGE REC VEHICLE
218
CONTINUE CHRG SESSION?
Y
N
220
TERMINATE CHRG SESSION

FIG. 4

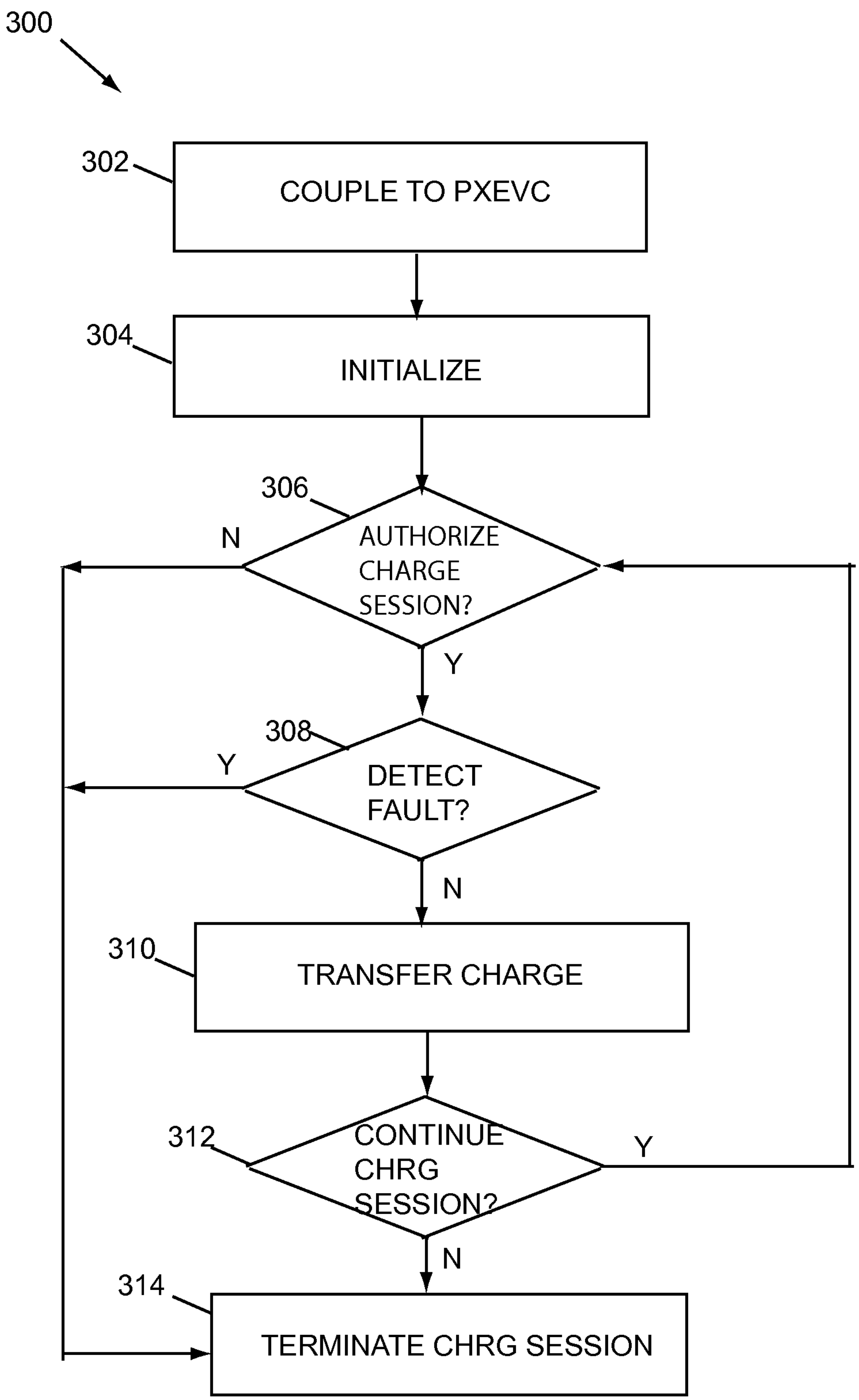
300
302
COUPLE TO PXEVC
304
INITIALIZE
306
AUTHORIZE CHARGE SESSION?
N
Y
308
DETECT FAULT?
Y
N
310
TRANSFER CHARGE
312
CONTINUE CHRG SESSION?
Y
N
314
TERMINATE CHRG SESSION

FIG. 5

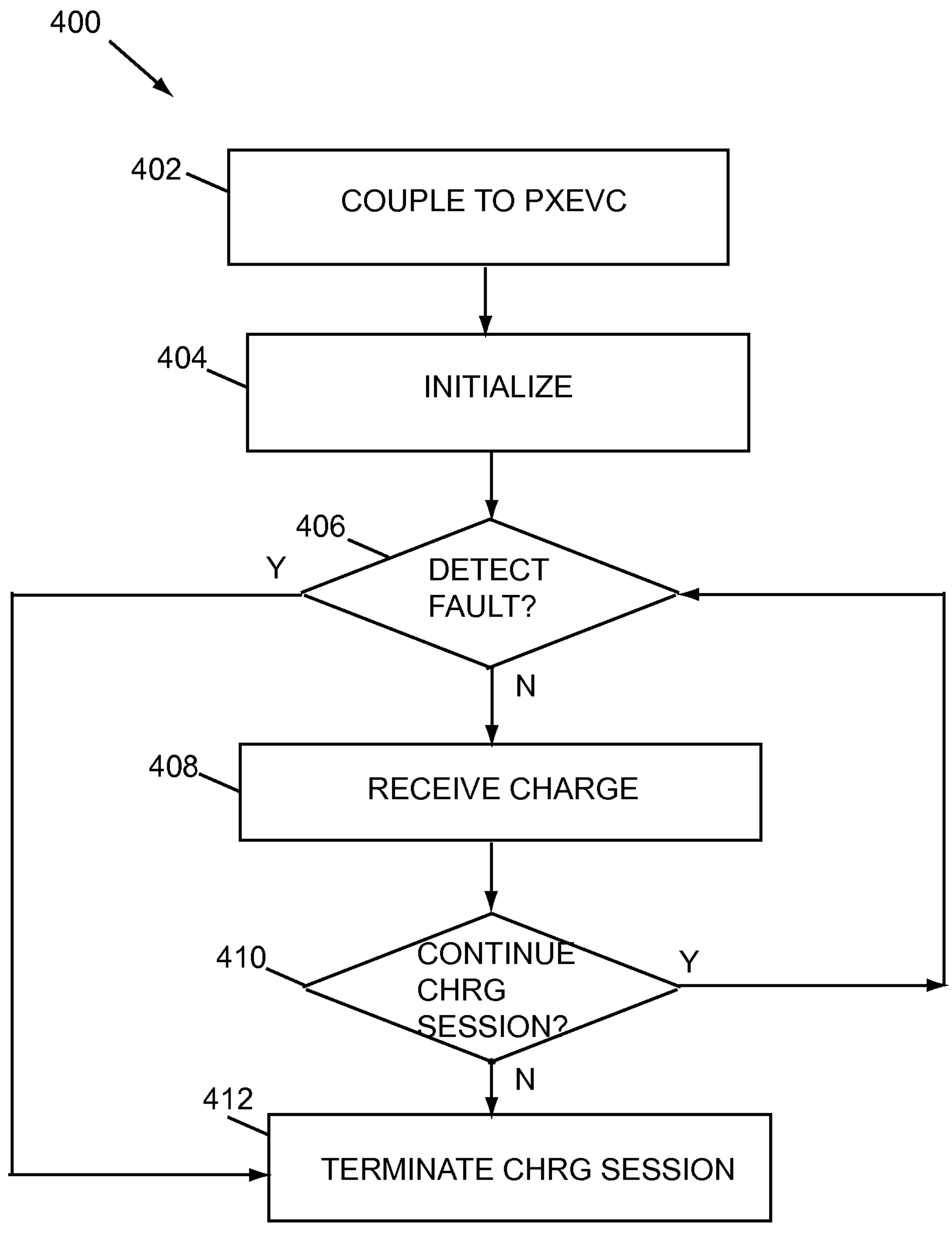
400
402
COUPLE TO PXEVC
404
INITIALIZE
406
DETECT FAULT?
Y
N
408
RECEIVE CHARGE
410
CONTINUE CHRG SESSION?
Y
N
412
TERMINATE CHRG SESSION

FIG. 6

METHOD AND APPARATUS FOR HIGH-VOLTAGE DC CHARGING OF BATTERY-ELECTRIC AND PLUG-IN HYBRID ELECTRIC VEHICLES

BACKGROUND OF INVENTION

1. Field of Art

This invention relates generally to charging of electrified vehicles, and more particularly to portable DC charging devices.

2. Background Art

In conventional and hybrid electric automobiles, an internal combustion engine can provide motoring power, and a low voltage battery can provide power for devices such as a starter motor, a cabin ventilation system, internal and external lights, an entertainment system and the like. In general, with a gasoline-powered engine a vehicle with full fuel reservoir can drive around 300 or more miles. When the fuel supply for the engine is depleted, it can be replenished with a brief stop at a service station. In desperate circumstances, when a vehicle is stranded without fuel in a remote area, a simple hose can be used to siphon gasoline from the fuel tank of an accommodating passing motorist who stops to assist. Similarly, when the charge of a conventional low voltage automobile battery drops below a required minimum, rendering a vehicle inoperable, the battery voltage can usually be boosted without too much difficulty or delay. For example, a set of inexpensive jumper cables, easily stowed at the vehicle, can electrically connect terminals of a functional battery to those of a depleted battery to complete a charging circuit that can reenergize the dead battery.

While a majority of automobiles continue to employ a gasoline engine, a quest to reduce emissions and increase exploitation of renewable energy drives an expanding market for electrically powered automobiles. Fully electrified vehicles that rely on a high voltage battery for motoring power have a driving range of around 100-200 miles per full charge. A high voltage battery is typically recharged by connection with an alternating current (AC) power grid. In most cases, a high voltage battery is coupled to the grid over an extended period during which there is no demand for the vehicle, such as during working hours, overnight at home, or during a prolonged parking period at a public charging station, such as at an airport while an operator is on travel.

For long-range travel, an operator can often plan a route and itinerary to include stops of sufficient duration at known recharging site locations. Should a battery unexpectedly run low during a motoring excursion, due, for example, to unexpected headwinds or other environmental factors that increase the amount of energy required for motoring, it is possible to recharge it at a charging station en route so that an operator can continue driving to his intended destination. One potential problem with such a scenario, however, is that charging stations for electrified vehicles are generally not as ubiquitous or conveniently located as conventional gasoline stations. Consequently, the likelihood of encountering one when a battery charge unexpectedly runs low is much less than that of happening upon a conventional service station.

Most charging stations provide lower power Level **1** or Level **2** charging by a process that can take up to several hours to charge a depleted battery. While long charging times can be acceptable when charge transfer is performed at predetermined times and locations, an extended recharging period can adversely affect travel plans when the process must be conducted unexpectedly. Concern regarding the possibility that a battery will become depleted while driving can discourage consumers from purchasing or employing electrified vehicles, depriving them personally, and the society at large, of the many benefits that an electric vehicle can offer.

SUMMARY OF INVENTION

The present invention provides methods and apparatus for high voltage charging of electrified vehicles. An example system can include a donor high voltage energy storage device (ESD) at a donor electric vehicle, a receiving high voltage energy storage device (ESD) at a recipient vehicle, and a portable cross electric vehicle charger (PxEVC) configured to controllably transfer energy from said donor ESD to said receiving ESD. In an example embodiment, a system can be configured for fast DC charging of the receiving ESD by the donor ESD.

A charging apparatus can include a first connector configured for coupling to a recipient vehicle, a second connector configured for coupling to a donor vehicle, and a controller unit for controllably transferring energy between said donor and recipient vehicles. An example charging apparatus can be configured to enable direct current (DC) charging of the recipient vehicle battery by the donor vehicle battery. In an example embodiment, a charging apparatus is embodied as a portable device that can be easily transported, for example it can be stowed at a donor or recipient vehicle. An exemplary charging apparatus can comprise a power conversion module configured to transfer energy between the donor and receiver batteries, and a processor module configured for communication with the donor and recipient vehicles and for controlling energy transfer by the power conversion module. In an example embodiment, a charging apparatus can perform voltage matching between the donor and receiver batteries.

A method for charge transfer can include coupling a charging apparatus with a donor vehicle, coupling a charging apparatus with a recipient vehicle, matching the donor vehicle battery voltage with the recipient vehicle battery voltage, performing a fault detection process, and controllably transferring charge between said donor vehicle battery and said recipient vehicle battery. In an example method, transferring charge between the donor and receiver batteries comprises fast DC charging.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an example system.
FIG. **2** shows an example system.
FIG. **3** shows an example system.
FIG. **4** shows an example method.
FIG. **5** shows an example method.
FIG. **6** shows an example method.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

As required, example embodiments of the present invention are disclosed. The various embodiments are meant to be non-limiting examples of various ways of implementing the invention and it is understood that the invention may be embodied in alternative forms. The present invention will be described more fully hereinafter with reference to the accompanying drawings in which like numerals represent like elements throughout the several figures, and in which example embodiments are shown. The figures are not necessarily to scale and some features may be exaggerated or minimized to show details of particular elements, while related elements may have been eliminated to prevent obscuring novel aspects.

The specific structural and functional details disclosed herein should not be interpreted as limiting, but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present invention. For example, while the exemplary embodiments are discussed in the context of a vehicle, it will be understood that the present invention need not be limited to that particular arrangement. Furthermore, control functions described as performed by a single module, can in some instances, be distributed among a plurality of modules. In addition, methods having actions described in a particular sequence may be performed in an alternate sequence within the scope of the appended claims.

Today, many electrified vehicles (EVs), such as plug-in electric vehicles (PEVs) and battery electric vehicles (BEVs) plug in to a power grid that provides alternating current (AC) charging sessions that usually last several hours. During a typical session, charging equipment at a vehicle (EV) can cooperate with electric vehicle service equipment (EVSE) at a charging station to coordinate the charge transfer from the grid to the vehicle. As discussed above, there are occasions in which a vehicle configured for AC charging is in need of additional charging options, preferably options associated with shorter charging sessions. The present invention can provide fast DC charging of a recipient vehicle using energy provided by a donor vehicle. In an exemplary embodiment, the invention can transfer charge via a process and interface similar to that employed between an EV and EVSE at a charging station. In an example embodiment, apparatus hardware, software and methods are configured to comply with industry standards pertaining to electrified vehicle charging, such as, but not limited to, Society of Automotive Engineers (SAE) 1772, International Organization for Standardization (ISO) 15118-1, 15118-2, 15118-3, and the German DIN Specification 70121, which are incorporated herein in their entirety by reference.

FIG. **1** shows an example system **100** in which a Portable Cross Electric Vehicle Charger (PxEVC) **102** can interface with a donor vehicle (DV) **104** and a recipient vehicle (RV) **106** to provide energy from a donor energy storage device (ESD) **108** at the to a recipient ESD **110**. For the purposes of this disclosure, a recipient vehicle is that vehicle having an ESD that is to receive additional energy. A donor vehicle is understood to be one having a (donor) ESD that is capable of providing energy. Under this definition, it is understood that a vehicle may be a donor vehicle at one instance in time, and a recipient vehicle in another instance. By way of example, but not limitation, the vehicles **104**, **106** are in the form of an electrified vehicle (EV) such as a battery electric vehicle (BEV) that is powered solely by electricity. However, it is contemplated that the invention can also be practiced with hybrid-electric vehicles (HEVs) and plug-in electric vehicles (PEVs).

In an example embodiment, the ESDs **108** and **110** can be in the form of a rechargeable energy storage system (RESS) configured to provide motoring power for an EV. By way of example, but not limitation, the ESDs **108**, **110** can be in the form of high voltage traction batteries or battery packs, such as lithium ion batteries. However, it is contemplated that an ESD can also be embodied as a high voltage capacitor or other electrical charge storage device configured to supply motoring power. In an example embodiment, energy can be provided to the recipient ESD **110** via a DC Level **1** or Level **2** charging process.

FIG. **2** shows an example implementation of the DC charging system **100**. In this example, the donor and recipient vehicles **104**, **106** can be manufactured in accordance with

Society of Automotive Engineers (SAE) standards for electrified automobiles, and as such, can be similarly equipped. By way of example, but not limitation, the PxEVC **102** can engage the charging inlet **112**, receive energy from the donor ESD **108**, and provide energy to the recipient ESD **110**. In an exemplary embodiment, the PxEVC **102** can be configured to cooperate with a control module **114** at the donor vehicle **104** to conduct a charge transfer process. The control module **114** can comprise hardware, software, firmware and/or some combination thereof and be configured to communicate with the PxEVC **102** in compliance with SAE DC charging protocols as well as control aspects of a charge transfer process. In an example embodiment, the control module **114** can comprise a dedicated module configured to authorize and implement a charge donation process, such as, but not limited to, software instructions executable at a microprocessor.

In a similar manner, the PxEVC **102** can be configured to engage a charge inlet **116** at the recipient vehicle **106**. The PxEVC **102** can be configured to cooperate with a control module **118** conduct a charge transfer process. Like the control module **114**, the control module **118** can comprise hardware, software, firmware, and/or some combination thereof and be configured to enable a DC charging process in compliance with SAE standards. In an example embodiment, the control modules **114**, **118** can be configured to perform and coordinate a variety of vehicle-related functions, including those unrelated to the charging process. Alternatively, the control modules **114**, **118** can be embodied as modules dedicated to a charging process and configured to cooperate with other vehicle modules as necessary.

By way of example, but not limitation, the PxEVC **102** can include a charge transfer control unit (CTCU) **120**, a first cable **128** coupled to a first connector **130**, and a second cable **132** coupled to a second connector **134**. In an example embodiment, the first and second cables **128**, **132** can be in the form of bundled cables configured for transmission of electrical control signals as well as charge current. In an exemplary embodiment, the connectors **130**, **134** can be in the form of a standard charging connector configured to interface with a charge inlet port at an electric vehicle. For example, the connectors **130**, **134** can be configured to engage charge inlets **112**, **116** respectively to electrically couple the CTCU **120** with the ESDs **108**, **110**. By way of example, the inlets **112**, **116** and the connectors **130**, **134** can be configured to operate in compliance with SAEJ1772 for DC charging of electrified vehicles so that connectors **130**, **134** can engage charge inlet ports of all automobiles designed in accordance with the globally recognized standards. As a result, the PxEVC **102** can provide a universal charging device compatible with automobiles of various makes and models. The connectors **130**,**134** can be configured to enable electrical connectivity between a plurality of conductors extending from the CTCU **120** within the cables **128**,**132** and a plurality of associated conductors at the charge inlets **112**, **116**.

The example CTCU **120** can comprise a power conversion module (PCM) **122** and a communication and control module (CCM) **124**. The PCM **122** can comprise a DC/DC converter circuit configured to receive current from a donor vehicle ESD and provide current to a recipient vehicle ESD. The CCM **124** can comprise hardware, software, firmware and/or some combination thereof. In an example embodiment, the CCM **124** can comprise a microprocessor or other processing device configured to communicate via predetermined protocols, monitor electrical power and connections, perform a fault detection process and control operation of the PCM **122**. For example, the CCM **124** can be configured to cooperate and communicate with control modules **114** and **118** at the donor and recipient vehicles **104**, **106** in compliance with ISO standards 15118-1, -2, and -3, and/or SAE J1772, pertaining to DC charging of electric vehicles. In an example embodiment, a PxEVC can be configured to perform a voltage-matching process between traction ESDs of donor and recipient vehicles. The exemplary CTCU **120** can further be configured with a user input means to receive input from a user, shown here by a human-machine interface (HMI) module **126**. By way of example, the HMI module **126** can be as simple as a power button for user input, or can include other features such as, but not limited to a display screen.

Referring to FIG. **3**, when engaged, the inlet **112** and connector **130** can form a conductive coupler **136** that mates conductors in one with corresponding conductors in the other. For example, the inlet **112** and the connector **130** can each include a plurality of terminals associated with various conductors as defined by SAE standard J1772. In accordance with the J1772 standard for DC charging, the inlet **112** and connector **130** can include 7 terminals, with, terminals **1** and **2** designated for Level **1** and **2** AC power exchange, terminal **3** designated for a ground connection, and terminals **4** and **5** designated for control signals. By way of example, terminal **4** can be used to conduct control pilot signals, and terminal **5** can be used to conduct proximity detection signals. Terminals **6** and **7** can be used for DC charging, such as but not limited to Levels **1**, **2** or **3** DC charging. By way of example, terminals **6** and **7** can electrically couple conductors that can, in cooperation with charging relays **140** and transfer relays **121**, connect the CTCU **120** with the ESD **110** for fast Level **2** DC charge transfer.

The charging inlet **116** and the recipient vehicle **106** can have similar configurations to those discussed above for the charging inlet **112** and donor vehicle **104**. The connector **134** and the inlet **116** can engage to form a conductive coupler **138** that can include the 7 terminals specified by SAE J1772. In an example embodiment, a pair of charging relays **142** can couple terminals **6** and **7** of the coupler **138** with the ESD **110** for Level **2** DC charge transfer. The PxEVC **102** can include a set of transfer relays **123** for coupling the PCM **122** with the terminals **6** and **7** for Level **2** charge transfer. In an example embodiment, the CCM **124** can be configured to control the opening and closing of the transfer relays **121** and **123**.

In the past, an EV has been configured for a charge transfer process in which charge is received, for example, when a vehicle ESD is AC charged by EVSE. During a typical recharge process (see standards referenced above), a recipient vehicle can control the process by requesting a certain voltage and/or current from the EVSE. A PxEVC can be configured to interface with a recipient vehicle in a manner similar to that of an EVSE at a charging station interfacing with a vehicle to be charged. In a method of the invention, however, a donor vehicle provides, rather than receives, electrical charge. Accordingly, in an example method it is contemplated that a donating vehicle can be configured to exert some degree of control over a charging process. For example, the control module **114** can be configured to exercise control over one or more aspects of the charge transfer. By way of example, the control module **114** can be configured to authorize a charge donation process, and, tasked with that function, can be configured to determine whether predetermined conditions, requirements, and/or and charging limitations are satisfied. Thus, the control module **114** can be configured to protect a donor ESD from unauthorized use and over-depletion.

In general, a DC charging session can include an initialization stage in which communications and charging parameters are established, a pre-charging stage, a charge transfer stage, and a session termination stage. FIG. **4** shows a flow diagram of an example method **200** that can be practiced at a PxEVC. At block **202** a PxEVC can be coupled to a donor vehicle. For example, the connector **130** of the PxEVC **102** can engage the charge inlet port **112** at the donor vehicle **104**. At block **204**, a PxEVC can be coupled to a recipient vehicle. By way of example, the connector **134** can be inserted into the charge inlet port **116** at the recipient vehicle **106**. In an example embodiment, the PxEVC **102** can interface with the recipient vehicle **106** in a manner similar to that of electric vehicle service equipment interfacing with the recipient vehicle **106** at a charging station.

At block **206** a PxEVC can be powered ON. By way of example, user input can be received at the HMI module **126** to power on the PxEVC **102**. For example, a user can depress a power button at the PxEVC **102** to turn it on. By way of further example, a PxEVC can be powered on automatically as a result of being plugged in to one or both charge inlets **112**, **116**, or as a result of keying on a donor vehicle to which it is coupled. In an example embodiment, the CTCU **120** can include a power supply (not shown), such as a low voltage battery configured to provide power for CTCU **120** operations.

In an example embodiment, at block **208** an initialization process can be performed. By way of example, an initialization process can include establishing communication links with, and receiving and/or exchanging donor and recipient vehicle charging parameters. In an example embodiment, successful coupling of the connectors **130**, **134** with the charge inlets **112** and **116** can prompt an initialization process in which the CCM **124** can establish communication with the control modules **114** and **118** and receive charging parameters therefrom. By way of example, charging parameters can include maximum current, maximum voltage, desired current, target voltage, etc. for ESD **108** and ESD **110**. Charging Level, i.e. Level **1** or Level **2** DC charging can be determined. Upon successful completion of the initialization process, the method **200** can proceed to block **210**. However, if the initialization process is not completed successfully, for example communication links failed to be established, or charging parameters provided by donor and recipient vehicles are incompatible, the method can end at block **220**.

At decision block **210** a determination can be made as to whether a charging session is authorized. In an example embodiment, a donor vehicle can exercise some degree of control over the charge process. By way of example, but not limitation, the control module **114** of the donor vehicle **104** can be configured to authorize a charge donation process. In an example method, a PxEVC can be configured to confirm authorization. By way of example, the CTCU **120** can be configured to receive a control signal or data message from the controller **114** that a charging session has been authorized. A fault signal indicating authorization denied, or a failure to receive an affirmative authorization signal, can lead to termination of the method at block **220**. In an example embodiment, a PxEVC can be configured to prompt the control module **114** for authorization notification. It is also contemplated that authorization can be confirmed by means other than a control or data message. For example, when a charge donation transfer process is authorized, the controller **114** can close the charging contactors **140** at the donor vehicle **104**, which can result in a voltage appearing at the terminals **6** and **7**. In an example embodiment, voltage sensing at the PxECU **102** can detect the voltage at the terminals **6** and **7**. The CCM **124** can be configured to use the voltage detection as an indication that the donor vehicle **104** has authorized a charge transfer.

At bock **212** a voltage matching process can be performed. In an example embodiment, the PxECU can be configured to first regulate the ESD **108** voltage to the controller **118** requested voltage. In an example embodiment, the CCM **124** can close transfer contactors **121** to allow current flow from the ESD **108** to the PCM **122**. In an exemplary method, the PxEVC **102** can establish a predetermined voltage at its output prior to commencing a charge transfer process. For example, if the ESD **110** is embodied as an HV battery configured to provide a voltage of 300V, the PxECU **102** can use energy provided by the donor ESD **108** at negotiated current levels to establish a voltage of around 300-301V, as determined by controller **118** request, at the PCM **122** output. In an example embodiment, the CCM **124** can be configured to close the transfer contactors **123** to provide a voltage to the terminals **6** and **7** of the coupler **138**. In an exemplary method, the PxEVC **102** can control output to ramp up voltage to match the voltage request of the controller **118**.

At block **214** a determination can be made as to whether a fault has been detected. An example method can include monitoring for a variety of faults at the vehicle and/or at the PxEVC. For example, most vehicles include an onboard diagnostic system designed to detect faults at the vehicle. In an example embodiment, the controllers **114** and **118** can be configured to cooperate with onboard diagnostic systems to be alerted of any faults that could compromise the charging process. Critical faults can result in termination of the method **200** by the PxEVC **102**. In an example embodiment, fault signals can be transmitted from a controller module at a vehicle to the CCM **124** at the CTCU **120** via the terminals **4** and **5**, which can be used for communication and control signals. In addition, a PxEVC can be configured to detect the presence of a fault, for example, a poor connection between a charge inlet and a connector, a communications link failure, a fault at the CTCU **120**, etc. In an exemplary embodiment, a fault detection process similar to that performed when an ESD is DC charged by EVSE at a charging station, such as that described by the J1772 standard can be conducted. By way of example, but not limitation, faults that can lead to termination of the charging process can include loss of safety ground, loss of high voltage isolation, loss of communication, and interruption of power transfer.

When no faults are detected, the method **200** can continue to block **216** at which charge is transferred. The control module **118** at the recipient vehicle **106** can close the charging relays **142** so that current can flow from the ESD **108** through charging relays **140**, coupler **136** terminals **6** and **7**, transfer relays **121**, PCM **122**, transfer relays **123** and charging relays **142** to the recipient ESD **110**.

In an example embodiment, a PxEVC can be configured for fast DC charging in accordance with Level **1** and Level **2** charging parameters described in the SAE J1772 standard specification. In an example embodiment, a charging current can be higher during bulk charging of the recipient ESD until a predetermined voltage is reached, then the charging process can be completed using a lower current. Voltage and current output at the PxEVC can be controlled by controlling output of a DCDC converter at the PCM **112**. By way of example, a PxEVC can be configured to perform DC charging of the recipient ESD with current ranging from zero to 200 amperes and voltage ranging between 200-500V.

At block **218**, a determination can be made as to whether a charge process is to continue. It is contemplated that a charging session can be stopped automatically by a PxEVC, a donor or recipient vehicle, or stopped manually by a user. In an example embodiment, the CCM **124** can be configured to receive input from one or more sources regarding a stop charging request. For example, a recipient vehicle can request that a charging session be terminated, when a desired or predetermined SOC has been reached. Accordingly, the CCM **124** can be configured to receive a stop charge request from the controller **118**. It is also contemplated that the controller **114** at the donor vehicle can request or command that a charging process be stopped, or indicate that a process is no longer authorized, when the donor ESD **108** SOC reaches or falls below a predetermined threshold or when other predetermined requirements, such as those required for authorization, are no longer satisfied. Thus the CCM **124** can thus be configured to receive input regarding termination from the controller **114**. In an example embodiment, a user may also terminate a charge transfer process. Accordingly, a PxEVC can be configured to receive user termination input, via the HMI **126** or other means, such as a means at the donor vehicle **104**, which can be communicated to the PxEVC. In addition, it is contemplated that in an example embodiment, a PxEVC can independently terminate a charging process. For example, the CCM **124** can be programmed with instructions that can include charging and termination requirements that may pertain to conditions and/or status at the donor and recipient vehicles and/or the PxEVC itself. Thus, at decision block **218**, the determination of whether to continue the charge process can depend on input from a variety of sources. If a determination is made to continue the charging the process, the method **200** can continue at block **214**.

A determination that the charging process is to terminate can lead to block **220**. In an example embodiment, a termination process can begin with a transition to a shutdown mode. During a shutdown mode the PxEVC and donor and recipient vehicles can be configured to return to a de-energized safe state so that the connectors **130**, **134** can be safely disengaged from the inlets **112**, **116**. The CCM **124** can reduce PxEVC **102** current output to zero. In an example embodiment, charging contactors **140** at the donor vehicle **104** can be opened, as well as transfer relays **121** and **123** at the PxECU, and charging relays **142** at the recipient vehicle **106**. When voltage across terminals **6** and **7** of the couplers **136**, **138** decreases to a desired level, the connectors **130**, **134** can be removed from the charge inlets **112**, **116**. In an example embodiment, a shutdown follows a normal charging termination sequence as outlined in ISO15118-1,-2 or SAE J1772.

FIG. **5** shows an example method **300** that can be practiced at a donor vehicle. At block **302** a donor vehicle can electrically couple a PxEVC. For example, charge inlet **112** can engage the connector **130** of the PxEVC **102**. In an example embodiment coupling of the connector **130** and inlet **112** can trigger operation of the control module **114**. Alternatively, the control module **114** can be powered on when the vehicle **104** is turned on, either by turning an ignition key, detecting a key in keyless ignition vehicles or depressing a vehicle power button.

At block **304** an initialization process can be performed. As discussed previously herein, an initialization process can include, among other possible actions, the control module **114** establishing communication with the CCM **124** and negotiating charging parameters such as current and voltage levels. As discussed above, failure to successfully complete the initialization process can prompt the CCM **124** to terminate the charge transfer process. In an example embodiment, failure to successfully complete initialization can prevent the control module **114** from continuing a charging process. At decision block **306** a determination can be made as to whether to authorize a charge donation process. In an example method, this determination can include determining whether one or more predetermined charging conditions are satisfied. By way of example, but not limitation, charging conditions can include vehicle **104** operator approval, and a minimum SOC at the ESD **108**. In an example embodiment, detection of a vehicle **104** key at the vehicle **104** can satisfy an operator approval requirement. For example, the control module **114** can be configured to cooperate with a vehicle control unit (not shown) at the vehicle **104** configured to detect presence of a key at the vehicle. The SOC of the ESD **108** can be determined by the control module **114** or by a separate vehicle module (not shown) with which the control module **114** is configured to cooperate. In an example embodiment, the control module **114** can be configured to compare the charge or charge surplus at the ESD **108** to a predetermined minimum charge or charge surplus requirement. When predetermined requirements are satisfied, a charge donation transfer process can be authorized by the control module **114**. In an example embodiment, the control module **114** can be configured to provide an authorization signal to the PxEVC **102**. The control module **114** can also close the charging contactors **140** when the charging process is authorized. As discussed previously herein, contact closure can be detected and interpreted by a PxEVC as confirmation that a charge session is authorized. The method **300** can continue to block **308**.

If charging conditions are not satisfied, an override option can allow a user to manually override the predetermined requirements. For example, the controller **114** can be configured to use operator input received at the vehicle **104** to bypass failure of the predetermined requirements and allow authorization of a charge transfer process. It is further contemplated that in an example embodiment, the control module **114** can be configured to perform an override operation under particular circumstances, without relying on user input. If an override option is exercised, charging can be authorized, and the method can continue to decision block **310**. However, if the predetermined conditions required for authorization are not satisfied, and no override option is exercised, then the method can terminate at block **314**. In an example embodiment, the control module **114** can provide a signal to the CCM **124** indicating that authorization for a charging process is denied.

At decision block **308** a determination can be made as to whether any faults are present. As described earlier herein, the control module **114** can be configured to check for faults at the donor vehicle **104**, for instance in cooperation with a vehicle control unit. In addition, it can be configured to receive fault signals from the PxEVC. If a fault has been detected, a charging session can terminate at block **314**.

If no faults are detected, the method **300** can continue to block **310** where the donor ESD **108** can transfer charge. In an example embodiment, the control module **114** can be configured to close the charging relays **140** to allow current to flow from the ESD **108** to the PCM **122** of the CTCU **120**. By way of example, the control module **114** can close the charging relays **140** in response to a prompt from the PxEVC CCM **124**.

The method **300** can continue to decision block **312** at which a determination can be made as to whether a charging session is to continue. In an example embodiment, the controller **114** can be configured to receive input regarding termination of a charging process. For example, a PxEVC can be configured to provide a stop charge session signal to the donor vehicle. Alternatively, a user interface or other means at a donor vehicle can allow operator input commanding that a charge session be stopped. If no termination input is received, the session can continue, and the method **300** can proceed to block **306**. At block **306**, the controller **114** can use conditions at the donor vehicle to determine whether the charge process should continue to be authorized. As discussed previously herein the controller **114** can determine whether predetermined charging requirements are satisfied, such as a minimum SOC at the ESD **108**. Thus, while the controller **114** can authorize the commencement of a charging process based on satisfaction of requirements, it can also discontinue a charge donation process by subsequently denying authorization, or providing a stop charging signal when those requirements are no longer satisfied. In this manner, the method **300** can protect the donor ESD **108** against becoming depleted to the point that its own voltage becomes unacceptably low. In an example embodiment, once a bypass option is exercised, it can remain in effect until a charge session is terminated, obviating the need for a user to repeatedly provide user input to exercise an override option.

If a determination is made at block **312** that a charge session is to no longer continue, at block **314** a charging session can be terminated. The controller **114** can trigger a shutdown mode at the donor vehicle **104** and open the relays **140** to disconnect the ESD **108** from the coupler **136** and the CTCV **120**.

FIG. **6** shows a flow diagram of a method **400** that can be practiced at a recipient vehicle. At block **402** a recipient vehicle can couple to a PxEVC. For example, the charge inlet **116** can engage the connector **134**. In an example embodiment, successful coupling can result in controller **118** activation. At block **404** the controller **118** can participate in an initialization process that can include establishing communications with the CCM **124** and negotiating charging parameters that can include voltage and current levels, as described in the SAE J1772 specification for DC charging protocols. As described above, a PxEVC can terminate a charging session if an initialization stage cannot be completed successfully. It is further contemplated that an example method can include termination by a donor or recipient vehicle upon failure of the initialization stage. When initialization is successful, the method **400** can continue to decision block **406**, where a determination can be made as to whether any faults are detected. For example, a fault detection method similar to that previously described herein as conducted at the donor vehicle **104** can be performed; i.e. fault detection can include checking for faults at the vehicle **106** and at the coupler **138**. If a fault is detected, a fault signal can be provided to the PxEVC **102** and the method can end at block **412**. If no faults are detected, the example method **400** can continue to block **408** at which electrical charge can be received. In an example method, the ESD **110** can receive charge in accordance with a charging profile that can include a pre-charging period. In an example embodiment, the controller **118** can close the relays **142** to electrically couple the ESD **110** with the PCM **122** to enable the charge transfer. Charge can be transferred at previously negotiated current levels to achieve an intended voltage.

At decision block **410** a determination can be made as to whether the charging session is to continue. In an example embodiment, a recipient vehicle can be configured to stop a charging session. For example, the controller **118** can monitor the state of charge of the ESD **110** and be configured to stop a charging event when a desired SOC is achieved. In an example embodiment, the controller **118** can provide a stop charging signal to the PxEVC **102**. However, it is contemplated that a PxEVC or donor vehicle can also terminate a session, in which case the controller **118** can be configured to receive a "stop charging" signal. At block **410**, in addition to checking SOC status, an ECU can check whether a stop session signal or other termination input has been received. If the charge session is to continue, the method **400** can proceed to block **406**. Otherwise, the charge process can be terminated at block **412**. In an example embodiment, the controller **118** can open the relays **142** during a shutdown mode that terminates the method **400**. In an exemplary embodiment, a PxEVC **102** can coordinate the termination process at donor and recipient vehicles. Termination can be performed in a safe manner so that voltages at the couplers **136**, **138** are reduced to zero or minimal levels prior to disengagement of the connectors **130**, **134** from the charge inlets **112**, **116**.

The present invention provides apparatus and methods that can be used to charge an electric vehicle high voltage battery using a donor vehicle high voltage battery. In an exemplary embodiment, a PxEVC can facilitate efficient fast DC charging that includes voltage matching and transferring charge at current levels acceptable to both donor and recipient vehicles. In an example embodiment, an automobile service vehicle can be equipped with a PxEVC to use in conjunction with a service vehicle donor battery in response to calls from stranded motorists. By way of further example, consumer vehicles can be configured to cooperate with a PxEVC to transfer charge so that a motorist having a PxEVC can provide or receive charge from another motorist, obviating the need to contact a roadside assistance service. A PxEVC can provide a portable, stowable recharging means that can be stored at a vehicle for ready access. The invention can provide security and peace of mind to operators of electrified vehicles, ameliorating anxiety about running out of battery power in an area without an accessible charging station. Equipped with a PxEVC, an operator can arrange to recharge an HV battery regardless of vehicle location. Planning for road trips can become much simpler with the assurance that recharging stops can be planned with another driver in advance at convenient locations, no more need to navigate to a specific recharging station location. Should a battery charge be depleted faster than anticipated due to unforeseen dynamic driving conditions, a driver can make arrangements in real time to meet someone at a safe location along his current route, reducing driver stress and improving driver safety.

In an example embodiment, a PxEVC charging interface can be similar to a charging interface at a typical public charging station. Communication and charging protocols described in universal standards discussed herein can be employed so that vehicles of various makes and models can enjoy the benefits offered by a PxEVC, regardless of traction battery chemistry. A PxEVC can monitor faults to provide a safe and effective charge transfer process. A PxEVC can be configured to implement one or more control algorithms to protect a donor ESD from over discharge. By requiring a donor vehicle authorization for an energy transfer process, a PxEVC can thwart energy theft attempts. A PxEVC can be configured to perform a voltage matching process prior to transferring energy between donor and recipient vehicles and implement a precharging stage at low current levels that can protect recipient ESD contactors. By providing a simple, efficient and convenient means for recharging a HV battery, a PxEVC can reduce operator anxiety and increase overall satisfaction with electrified vehicles.

As required, illustrative embodiments have been disclosed herein, however the invention is not limited to the described embodiments. As will be appreciated by those skilled in the art, aspects of the invention can be variously embodied, for example, modules and programs described herein can be combined, rearranged and variously configured. Methods are not limited to the particular sequence described herein and may add, delete or combine various steps or operations. The invention encompasses all systems, apparatus and methods within the scope of the appended claims.

What is claimed:

1. A system, comprising:
- a donor energy storage device (ESD) at a donor electric vehicle;
- a recipient ESD at a receiving electric vehicle; and
- a self-contained portable cross electric vehicle charger (PxEVC) configured to releasably couple a first charging interface at said donor electric vehicle and releasably couple a second charging interface at said receiving electric vehicle, said PxEVC configured to controllably transfer power from said donor ESD to said receiving ESD.

2. The system of claim **1**, wherein said PxEVC is configured to to match an output voltage at said PxEVC to a requested recipient ESD voltage prior to transferring power from said donor ESD to said recipient ESD.

3. The system of claim **1**, wherein said PxEVC comprises a power conversion module configured for DC/DC power conversion.

4. The system of claim **1**, wherein said PxEVC comprises a processing module configured for communication with said donor and recipient vehicles.

5. The system of claim **1**, wherein said PxEVC is configured to detect a fault.

6. The system of claim **1**, wherein said PxEVC is configured for fast DC charging of said recipient ESD.

7. A stand-alone charging apparatus for an electrified vehicle, comprising:
- a charge transfer control unit (CTCU) configured to transfer energy between a donor electric vehicle and a recipient electric vehicle;
- a first cable coupled to said CTCU and terminating with a first connector configured for releasably coupling a first charge interface at said donor vehicle;
- a second cable coupled to said CTCU and terminating with a second connector configured for releasably coupling a second charge interface at said recipient vehicle; and
- wherein said apparatus is configured to controllably charge a recipient energy storage device (ESD) of said recipient vehicle using energy from a donor ESD of said donor vehicle.

8. The apparatus of claim **7**, wherein said apparatus is configured to enable DC charging of said recipient vehicle ESD with current ranging between zero and two hundred amperes.

9. The apparatus of claim **7**, wherein said apparatus is configured to enable DC charging of said receiving vehicle ESD with voltage ranging between 200 and 500 volts.

10. The apparatus of claim **7**, wherein said CTCU comprises a power conversion module having a DC/DC converter and configured to transfer energy between said donor and recipient ESDs.

11. The apparatus of claim **7**, wherein said CTCU comprises a processing module configured for controlling said power conversion module.

12. The apparatus of claim **7**, wherein said CTCU comprises a processing module configured for communication with said donor and recipient vehicles.

13. The apparatus of claim **7**, wherein said CTCU comprises a human machine interface (HMI) configured to receive operator input.

14. The apparatus of claim **7**, wherein said CTCU is configured to provide an output voltage at said power conversion module that matches a requested recipient ESD voltage prior to charging said recipient ESD.

15. The apparatus of claim **7**, wherein said apparatus is portable.

16. The apparatus of claim **7**, wherein said apparatus is configured to provide DC power to said recipient vehicle ESD.

17. A method, comprising:

a first cable of a stand-alone portable cross electric vehicle charger (PxEVC) coupling a first charge interface at a donor vehicle;

a second cable of said PxEVC coupling a second charge interface at a recipient vehicle;

said PxEVC detecting presence or absence of a fault; and

said PxEVC controllably DC charging said recipient vehicle energy storage device (ESD) using said donor vehicle ESD.

18. The method of claim **17**, further comprising said PxEVC establishing a communication link with said donor vehicle and with said recipient vehicle.

19. The method of claim **17**, further comprising said PxEVC providing an output voltage that matches a requested recipient vehicle ESD voltage.

20. The method of claim **17**, further comprising said PxEVC confirming said donor vehicle authorization for said charging.

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